Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of	)	
	)	
Inquiry Regarding Software Defined Radio	)	ET Docket No. 00-47
	)	
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COMMENTS OF MOTOROLA

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SUMMARY

Motorola commends the Commission for issuing this *Notice* on Software Defined Radio (SDR). Motorola has been a leader in the development of SDR technologies, and we are pleased to share our knowledge of these technologies with the Commission.

SDR technology is not a single technological breakthrough. Rather, it is a collection of implementation technologies that enable greater flexibility in radio products. SDR can change the functionality of a radio to appear as a reconfiguration of an array of hardware elements, or may take the form of actual software implementation of radio capabilities, including the ability to reprogram an entire protocol stack. The common bond among all SDR technologies is the practical ability to reprogram, or reconfigure, a given radio function after the point of product manufacturing.

While SDR holds much promise for advancing radio technology, it will not replace conventional spectral management policy; nor does it remove the need for spectrum planning by the U.S. Government. Allowing *ad hoc* spectrum allocation, or allowing services to be placed adjacent to one another without proper consideration of interference scenarios, will not serve the public interest, nor will it ensure optimal use of available spectrum. Efficiency of the spectrum will be determined by the air interface and system deployment standards. Therefore, to operate over increasingly wider ranges of RF frequencies requires a careful assessment of the interference scenarios between various portions of spectrum and the services operating in that spectrum.

For example, it would be unreasonable to expect a commercial, high-sensitivity data receiver, operating in an otherwise-available band, to be made subject to very intense

signals from a television transmitter operating at very high power levels. Similar interference scenarios between systems of widely varying transmitted power levels, significantly different occupied bandwidths, and sensitivities to varying types of interfering signals might be the outcome of futuristic, automated spectrum allocation schemes. SDR is not a panacea nor is it a substitute for advances in programmable-filter technologies, high-dynamic range data converters, RF amplifiers, or the improved interference-mitigation techniques that are not foreseeable in the near future.

SDR technology will, however, enhance many capabilities found in current radio products and the systems and networks that employ those products. Over the next 5 to 10 years, these enhancements will be largely be constrained within the context of existing network standards, especially given that SDR will not innately propagate new standards. SDR will allow for significant flexibility in hardware platforms, which will benefit the consumer, the network operator, and the equipment manufacturer. SDR technology will also advance multimode, multiband, and multifunction efficacy, while empowering a broader range of robust applications at the user interface.

These technologies have been materializing intermittently over the last several years, and products employing some of these technologies are now available. SDR products designed for unique military applications are currently in production. As these underlying technologies progress, future commercial products will incorporate them and provide ever-increasing capabilities. In the commercial markets, these will generally be limited to specific features in order to minimize costs. Many practical factors will moderate how SDR is adopted commercially. SDR solutions currently carry penalties in cost, size, and power dissipation, compared to single-purpose equipment.

Examples of areas where advancing technology will facilitate SDR implementation include: antenna, filtering, A/D conversion, and Digital Signal Processor (DSP) technologies. Antenna technology, for example, is one problematic area if disparate frequency ranges are to be supported by a software defined radio. Cost-effective commercial antenna technology still tends to be narrowband in nature to achieve both the desired gain and directivity for proper system operation as well as the physical size that is acceptable to local zoning agencies and the public's aesthetic expectations. It is also very difficult to obtain economical wideband frequency selection. While data converter technology continues to improve, there are currently significant limitations in reconfigurable signal processing solutions. General purpose DSP technology alone is not commercially viable for the demanding functions of the high-speed processing required for channelization, signal detection, modulation and demodulation.

It is anticipated that these technology challenges will be progressively addressed over the next decade. Within three years, there will likely be an increasing number of software-defined fixed station products implemented in order to lower costs by supporting multiple, simultaneous RF frequencies. In five to ten years, key technology areas such as broadband antennas and RF devices, data converters, and reconfigurable signal processors can be expected to extend SDR technology. Cost improvements will lead toward adoption of SDR as the universal platform across a manufacturer's product portfolios. Software download and security technologies, under the control of the manufacturers, will permit sophisticated download scenarios, such as over-the-air download.

Equipment manufacturers will converge on common hardware platforms so that they can support many different air interfaces and thus reduce manufacturing costs. From a manufacturer's perspective, SDR could unify the various radio designs into one platform design that would rely on software to alter the characteristics of the radio rather than having to design new hardware each time a new radio is designed or a new feature is added. This could speed up time-to-market for deploying future air interfaces and subsequent feature enhancements.

Network operators could extend the useful life of infrastructure equipment as air interfaces evolve. The extent to which 'future proofing' the air interface is practical and cost-effective is dependent on the complexities of the underlying hardware platform. New hardware will have to be developed to keep up with these changes.

Commercial handsets today employ software control of various radio parameters. The long operating life of most infrastructure equipment and the slow rate at which new industry standards have historically come forth has limited the need for software control to those functions that meet requirements of the relevant industry standard. More recently, however, standards are evolving so rapidly that it is imperative that software control be flexible.

SDR technology will prove to be an effective tool in encouraging greater interoperability among public safety systems. It can also facilitate interoperability among communications networks and commercial services, but this will be dependent upon competitive factors. However, SDR technology will at least facilitate transition to new standards, making it possible for multi-regional network operators to offer wider coverage areas with minimum investment in new hardware (such as unique radios). In the same manner, SDR can facilitate roaming agreements between disparate standards.

SDR technology does not inherently compromise the FCC's current regulatory policies. Therefore, no immediate FCC rule changes are required to accommodate it. To understand the implications of SDR technology on the current FCC rules, it is instructive to consider that SDR technology will not result in, nor will network systems sanction, products that operate outside the context of defined network standards. Therefore, an SDR product must be approved for each mode of operation for which it is intended.

SDR will have the ability to change equipment software "on the fly" once a radio has been manufactured, shipped, and put into service. Authentication and security issues must be controlled by industry to insure that new code releases do not cause a violation of emissions and safety regulations. As security is so critical, equipment manufacturers must take responsibility for ensuring that their products are tamper-proof and that all authorized software for SDR products is certified. Motorola supports open interfaces at the application layer of the OSI Model, and encourages an energetic and competitive third-party application software market. However, we believe that lower-layer software interfaces should remain under the control of the equipment manufacturer.

Motorola urges the Commission to carefully review all the comments filed in this proceeding concerning the underlying technologies and implications of SDR. SDR is an important technology and one that promises significant future benefits, but it is not a quick and simple solution for complex spectrum management problems.

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COMMENTS OF MOTOROLA

Motorola, Inc. (hereinafter Motorola) submits these comments in response to the *Notice of Inquiry* in the above-captioned proceeding.[1]

Top Motorola Messages

- ✓ SDR is not an air interface standard; it is a collection of system and implementation technologies.
- ✓ Practical constraints in product cost, size, and power dissipation will pace the rate of commercial adoption.
- ✓ SDR technology can be an important tool to improve interoperability between public safety agencies.
- ✓ SDR is not a replacement for conventional spectral management policy.
- ✓ Spectral efficiency is determined by the air interface and system deployment standards.
- ✓ SDR technology will not inherently cause, nor will network systems permit, the operation of products outside the context of defined network standards (e.g., GSM).
- ✓ No immediate FCC rule changes are required to accommodate SDR technology.
- ✓ Equipment manufacturers should control software interfaces that affect emissions and safety.

1. Introduction

[1] Inquiry Regarding Software Defined Radios, ET Docket No. 00-47, *Notice of Inquiry*, FCC 00-103, released March 22, 2000 [hereinafter *Notice*].

Motorola commends the Commission for issuing this *Notice* on Software Defined Radio (SDR). It is important that the Commission acquire a thorough understanding of SDR, what it is capable of, and what are the reasonable future expectations for the technologies that constitute SDR. Motorola has been a leader in the development of SDR and we are pleased to share our knowledge of these technologies with the Commission. Motorola is one of the founding members of the SDR Forum, an international consortium of commercial and industry companies. More than 80 telecommunications manufacturers bring their unique expertise to this organization, which was formed to develop architecture and forge agreement on open standards for SDR development. Motorola has incorporated the SDR forum architecture into a family of software redefinable solutions called Wireless Information Transfer Systems (WITS).

In addition to this expertise in SDR developed for national defense and public safety uses, Motorola is examining SDR potential in a number of our major business segments, including Personal Communications; Network Systems; Semiconductor Products; and Integrated Electronic Systems. These comments reflect the knowledge gained of SDR capabilities and implications from throughout this diverse set of business units.

2. Technology (FCC NOI Questions 1-5)

Summary of Questions

What capabilities will SDR bring compared with conventional technology? What is the current state of SDR technology, and what are the time scales for future developments? When will SDR products be commercially available?

Key Motorola Messages

- ✓ SDR is a collection of system and implementation technologies that enable greater flexibility in radio products.
- ✓ SDR technology is not a "big bang" technology. Emergence of SDR has already begun; evolution will continue that will enable new and compelling wireless applications and services.
- ✓ The primary capabilities associated with SDR are:
  - ➢ Efficient realization of multimode, multiband, multi-featured radios
  - ➢ Post-manufacture re-programmability across the entire protocol stack
  - ➢ Common hardware platforms for manufacturers
- ✓ Practical constraints in product cost, size, and power dissipation will pace the rate of commercial adoption.

2.1: SDR Capabilities.

SDR technology will enhance many capabilities found in radio products and the systems and networks that employ those products. Over the next 5 to 10 years, these enhancements will be largely constrained within the context of existing network standards. In this timeframe, SDR technology will not fundamentally alter the performance of networks that are based on existing standards. It will, however, allow for significant flexibility found in hardware platforms, which will benefit the consumer, the network operator, and the equipment manufacturer. These capabilities are explored in detail in this section. In later sections, the prospects for additional benefits in interoperability, and spectral efficiency will be discussed.

SDR technology will enable significant advances in multimode, multiband, and multifunction capabilities, while enabling a broader range of more powerful applications at the user interface. The ability to download software across the protocol stack, through a variety of means, will allow for mass customization of subscriber products. After being sold, products will be able to easily adopt new software releases as they become available.

SDR implies not only the ability to change the protocols, coding, and over-the-air security mechanisms (e.g., encryption algorithms), but also the ability to change RF parametric capabilities such as operating frequency, transmitter output power and modulation characteristics. SDR technology will include cryptographic authentication of its software to minimize the likelihood of software corruption.

Handoffs between dissimilar systems will become possible without the loss of the connection. Simultaneous voice connections and data connection on a single device may be possible. It may also be possible for a terminal to act as a router, moving data via different air interfaces at data sources and destinations.

2.2: Comparison to Conventional Technology.

Capabilities enabled by SDR, not found in current radio technology, include the ability to significantly change the modulation supported by the radio's transmitter and receiver, and the ability to process signals of significantly different RF bandwidths. SDR would also permit radio communication to support different signaling and bearer protocols. Interference mitigation techniques and adaptive array processing would allow for improved RF link performance which could potentially lead to higher spectrum efficiencies or improved service offerings.

2.3: Benefits to Manufacturers and Network Operators.

SDR will become increasingly attractive to equipment manufacturers as they seek to converge on a common hardware platform that can support many different air interfaces and thus reduce manufacturing costs. From a manufacturer's perspective, SDR could provide a benefit by unifying the various radio designs into a common platform that would rely on software to alter the characteristics of the radio rather than redesigning new hardware. This could lead to faster introduction of new products to market and to faster deployment of new air interfaces or enhancements to those interfaces.

From a network operator's perspective, SDR has the potential to extend the useful life of the infrastructure equipment as the air interfaces evolve; however, there is a limit to how much "future-proofing" is possible. As the air interface evolves to levels of complexity that exceed the capabilities of the underlying hardware platform, new hardware will have to be developed to keep up with these changes. This is analogous to the PC industry; as software evolved to provide ever-increasing features, it ran slower and slower on older hardware platforms. At some point, the underlying hardware platform will no longer support the new software, and a new hardware platform is required. The same will happen with SDR hardware in time.

2.4: Software Controlled Features.

The means by which software can alter the parameters of a given radio function can and will vary. The software control may take the form of a reconfiguration of an array of hardware elements, or it may take the form of actual software implementation of radio functions. SDR encompasses all such possibilities. The common bond among all SDR implementations is the practical ability to reprogram, or reconfigure, a given radio function after product manufacturing.

2.5: SDR Capabilities Found in Current Handheld Products.

Today, many handheld radio features are software controlled. Some of these features are characterized by software control of a hardware subsystem. Writing a value to a register controlling a frequency synthesizer controls operating frequency. Output power is controlled by writing a value to a D/A converter input register. Rake receivers for Code Division Multiple Access (CDMA) are often implemented as hardware blocks with parameters settable through software. Large Viterbi decoders and turbo decoders are also implemented in hardware but controlled through software. Other features are implemented directly in software, not simply under software control. Modulation formats can be created by Digital Signal Processor (DSP) computations that create in-phase and quadrature components for a quadrature modulator. Most of the signal processing for the Global System for Mobile Communications (GSM) can be implemented on a DSP. Typically, only those features that are defined as variable by the relevant standards can be changed after the point of manufacturing.

The transmission protocols at Layers 1, 2, and 3 in the OSI protocol stack model are almost exclusively under software control. While these may not directly affect the fundamental physical layer characteristics of the radio for such parameters such as transmission frequency, modulation and output power, these protocols are a significant part of all wireless communication standards that ensure interoperability between different manufacturers' equipment. These protocols are also some of the most flexible aspects of today's wireless communications standards that permit evolution of the standards to enable new service offerings, enhanced capacity, and deployment flexibility for the network operator.

2.6: SDR Capabilities Found in Current Infrastructure Products.

Current generation infrastructure equipment shares most of the characteristics mentioned for handheld devices. In addition, base station equipment does have several unique factors to consider. Given the long operating life of most infrastructure equipment, and the slow rate at which new industry standards have historically emerged, the need for software control of a radio has been limited to those functions that pertain to meeting the requirements of the relevant industry standard. With the increasing speed at which standards are now evolving, with different modulation schemes, new protocols, and the desire to maximize the useful life of the infrastructure, there will be an inherent need to increase the flexibility of the radio functionality through software.

Currently, there is considerable work being performed in the industry for enhancing both transmitter and receiver performance via interaction with antenna subsystems through software algorithms which perform actions such as RF beam forming, interference rejection, and multi-user detection. All of these improvements are aimed at providing an enhanced RF communications network.

Further improvements in several technologies will enable multicarrier base stations that meet the relevant regulatory requirements around the world. This, too, has the potential for reducing the cost of infrastructure equipment intended to support a high number of users rather than designing a base station with multiple single frequency radios that are then combined together. Indeed, multicarrier base station equipment does exist today and is deployed on a limited basis.

2.7: SDR in the Military - the WITS System.

SDR for military radio applications has undergone significant development, which has led to currently available products. Motorola's WITS 6004[2], for example, is a full duplex, 4-channel radio system.

Technical efforts to develop the WITS system began in 1992 under the Speakeasy Program, sponsored by the U.S. Air Force and developed by Motorola, together with several different partners in the Federal Government. Originally designed to meet U.S. Department of Defense (DoD) requirements in programs like Joint Tactical Radio

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[2] Motorola has produced a family of software redefinable solutions called Wireless Information Transfer Systems (WITS). Originally designed to meet U.S. Department of Defense (DoD) requirements in programs like Joint Tactical Radio System (JTRS) and Digital Modular Radio (DMR) for software definable radios, this WITS-Enabled™ technology has been expanded to address similar needs for interoperability faced by state and local government agencies, especially in joint operations with federal agencies. For example, the WITS systems, when programmed with the Project 25 protocol, will allow the WITS system to interoperate with systems like Motorola's ASTRO 25™ or other Project 25 vendors to meet this need. **WITS 6004** – This flagship SDR product is a 4-channel, full-duplex gateway system. The 6004, with a size of 17.5"W x 19.25"H x 22"D, is mainly designed to be used in fixed-location sites and can serve as a router to move voice and data communications over a variety of wireline and wireless networks.

System (JTRS) and Digital Modular Radio (DMR) for software definable radios, this WITS-Enabled™ technology has been expanded to address similar needs for interoperability faced by state and local government agencies, especially in joint operations with federal agencies. For example, the WITS systems, when programmed with the Project 25 protocol, will allow the WITS system to interoperate with systems like Motorola's ASTRO 25™ or other Project 25 vendors to meet this need.

Each channel in the WITS system can control the following internal radio functions via software, or remote control by user interface:

- Carrier frequency from 2 MHz to 2 GHz
- Bandwidth selection filters from 5 KHz to 2 MHz
- Transmit and receive
- Waveform function (AM, NBFM, WBFM, MFSK, MPSK, OQPSK, MQAM, CPM, others as defined and created)
- Waveform spreading (direct spread and other DoD techniques)
- Media Access (FDMA, TDMA, CDMA, other)
- Encryption/decryption algorithms, modes, keys
- Voice and data source coding (vocoder, etc.)
- Voice and data network interface protocols (VOIP, TCP/IP, UDP, ATM, etc.)
- Cross channel bridging (repeater, or multi channel)
- Diversity (selection or optimal combining)
- RF output power
- Squelch sensitivity
- Audio Volume

2.8: Current State of SDR RF Technology.

Current multiband radios have parallel RF hardware to serve the often-disparate bands a radio is likely to encounter. Such duplication of hardware not only impacts the material and assembly cost of the radio, but also the size and weight. In spite of these inefficiencies, it is often more economical to populate a radio with multiple lower-cost, performance-optimized point solutions than to develop a family of generic components that may provide adequate performance at the cost of competitiveness in one or more areas (e.g., power efficiency).

Because radio front-ends contain components that are highly sensitive to their own geometry and materials as well as their surroundings, the demand for repeatability of these components comes at the cost of inflexibility. Examples of such components are antennas, isolators, and preselector filters. Preselector filters are typically required to have uniform passband performance, high selectivity and well-defined frequency responses. These characteristics are realized through either lithographic (for SAW-type filters) or precision machining (for ceramic block filters) processes. Requiring such a component to be reconfigurable introduces the need for (often lossy) tuning or switching elements that degrade the performance compared to a fixed solution. If band definitions and air interfaces were defined with such limitations in mind, they of course could be accommodated. However, existing air interfaces have always presumed certain front-end technologies in their definition.

2.9: SDR's Enabling Technologies.

SDR should not be thought of as a "big bang" technology that is waiting to be developed and deployed. In fact, SDR is a collection of many technologies, which when used in unison, can enable greater flexibility in radio products. Examples of SDR enabling technologies include:

- System Simulation and Software Development Environment
- File Management System
- Security Processes
- Reconfigurable Signal Processing
- High Performance Data Converters

- Simplified Multiband Rx and Tx
- Integrated Switched Filters
- Broadband Antennas
- Mode Switcher and Software Download

Emergence of these enabling technologies has already begun, and products employing these technologies are now available. As described earlier, SDR products designed for military application are currently in production. As these underlying technologies progress, future commercial and consumer products will incorporate them and provide ever-increasing capabilities. In commercial markets, these capabilities will generally be limited to specific features in order to keep costs to a minimum.

An example of a current system that employs some of these enabling technologies is the GSM system, which has evolved to include the General Packet Radio Services (GPRS). GPRS, in turn, has evolved within the last two years to provide higher data rate capability through an enhancement to the standard known as EGPRS (Enhanced GPRS). EGPRS provides for two different modulation formats that include GMSK and 8-PSK. The modulation is dynamically adapted according to the needs of the user and the characteristics of the RF channel. New products supporting EGPRS will appear commercially before the middle of 2001. These radios are also expected to contain adaptive signal processing that will support blind detection and reception of either the GMSK or 8-PSK modulation formats. Because the two modulation formats have different peak-to-average characteristics, the transmitters will likely be designed to handle the transmissions in slightly different ways to ensure compliance with the requirements of the various regulatory bodies around the world. These radios will also support the various protocols that enable simultaneous support of GSM circuit-switched services as well as GPRS and EGPRS packet-switched services.

2.10: Limitations on Commercial Adoption of SDR.

Despite the early examples of SDR viability, many practical factors remain which will moderate the rate of commercial adoption of SDR. SDR solutions currently carry penalties in cost, size, and power dissipation, compared to single-purpose equipment. Other practical issues center around data converters that typically cannot operate in radio environments where signal strength variations may exceed 100 dB. The intensive signal processing requirements of CDMA and WCDMA systems are a serious obstacle to the development of handheld software-based cellular SDR terminals. Efficient broadband antennas that fit a handheld terminal present technical challenges. Many 2G and 3G cellular standards are based on CDMA protocols that require full duplex operation. The need for duplex filtering imposes significant restrictions on the frequency adaptability of radios. The next few paragraphs will examine some of the critical technical challenges facing the widespread adoption of SDR.

2.11: Challenges in Antenna and Filter Technology.

Antenna technology is one problematic area if wide frequency ranges are to be supported by a software radio. Cost-effective commercial infrastructure antenna technology still tends to be narrowband in nature to achieve the desired gain and directivity for proper system operation, and physical size that is acceptable to local zoning agencies and the public's aesthetic expectations. This becomes a significant concern if, for example, a new frequency band is made available to a service provider or system operator for new services or an expansion of existing services. Having a software radio alone would be of limited value with having to put up a new antenna system to support each new frequency band or without having the current antennas be capable of supporting the new frequencies. The addition of multiple antennas is technically possible, but practically problematic because of the negative aesthetic impact and zoning problems associated with adding antennas. As more disparate frequency bands are added to the set of possible operating frequencies in a software radio, this problem becomes even more acute.

Broadband or multiband antennas are difficult to implement in handheld terminals as well. Small size, aesthetic concerns, and performance requirements all make designing antennas very challenging.

It is also very difficult to obtain wideband frequency selection in an economical way. Possible solutions include switched filtering and tunable filtering. The latter technology is relatively expensive and limited in power handling capability. If the required frequency tuning range is limited, then the possible solutions become more cost-effective and likely to be technically feasible. There is still the problem of high transmitter output powers for some services that may preclude the use of tunable RF filtering for the near term.

2.12: Challenges in Signal Processing and Data Converter Technology.

There are currently significant limitations in reconfigurable or programmable digital signal processing solutions. General purpose DSP technology alone is not capable of performing the demanding functions of high speed processing required for channelization, signal detection, modulation, and demodulation. Most current implementations use some form of ASIC implementations to minimize the cost, size, and power consumption of infrastructure equipment. This is readily seen in infrastructure equipment designed for the IS95 CDMA standard, and to some degree, the GSM digital cellular system. It is becoming common practice to parameterize the ASICs to provide some degree of flexibility by allowing certain attributes of the ASIC to be configured via software.

Additionally, DSPs that are augmented with special purpose hardware acceleration are common. Even with this kind of software configurability, significant limitations remain. For example, it is unlikely that a radio designed to support the ANSI-136 or GSM Time Division Multiple Access (TDMA) standards could easily be modified through software to support the IS95 CDMA standard. The primary reason for this is that the computational complexity of the CDMA system is considerably higher than the GSM system that is itself more complex than the ANSI-136 system. The radio architectures tend to be different as well.

Field Programmable Gate Array (FPGA) technologies are another approach to high-performance reconfigurable digital signal processing and are found in some current implementations of infrastructure equipment; however, FPGA technology is not optimized for communications processing. However, it is well suited to providing basic radio timebase generation that is needed for all modern digital air interfaces, and a broad range of signal processing that cannot be anticipated at the time of equipment manufacture. Oversampling clocks, bit clocks, frame clocks, and other timing signals that are needed by the radio can all be generated easily with this technology via software programming. This is beneficial in that it allows manufacturers to develop a product more quickly than with an ASIC solution for communication signal processing; however, it tends to be more expensive for commercial high-volume productions.

Efforts are underway within the industry to develop configurable hardware under software control. This hardware would be a generic computing platform that can perform signal processing for one or more channels of a communication system. Software would be used to configure the programmable hardware to perform whatever functions are necessary for the desired air interface or multiple air interfaces. This can include modulation, demodulation, detection, and IF filtering functions.

Data converter technology continues to improve and there are various programs within the industry to dramatically improve the state of the art in data converter technology. Progression of SDR will be significantly paced by these developments. The cost of new converter technology is expected to be acceptable for infrastructure use. Multiple radios, each tuned to a specific portion of the available spectrum, will likely be required for the foreseeable future because of data converter bandwidth limitations.

2.13: SDR Timeline.

It is anticipated that these technical challenges will be progressively addressed over the next several years. By 2003, there will likely be an increasing number of software defined base station products that will be targeted at driving down costs by supporting multiple, simultaneous RF frequencies. Support of 3G cellular standards will drive products to utilize increasingly broadband RF devices, and more flexible signal processing solutions. Cost constraints will likely drive manufacturers to focus on multimode and multiband products which address very specific market scenarios. After-sale customization, enabled by downloadable software architectures, may emerge.

Between 2005 and 2010, advancements in key technology areas such as broadband antennas and RF devices, data converters, and reconfigurable signal processors will extend the practical capabilities of SDR. Cost improvements will lead toward adoption of SDR as the common platform across a manufacturer's product portfolios. Software download and security technologies will permit more sophisticated download scenarios, such as over-the-air download. The emergence of the third-party software market will continue, with the emphasis placed on applications for the user interface. Safety, security, reliability, and cost constraints will force equipment manufacturers to tightly control the software interfaces that effect radio transmission and reception.

2.14: International SDR Activity.

In the United States, the FCC and its Technical Advisory Council have been active and supportive in the advancement of SDR. Other international regulators have begun to examine the issues and opportunities associated with this technology. International collaboration between regulatory agencies and industry forum is essential, given that much of the opportunity associated with SDR inherently deals with issues of multiregional, multinational roaming, and interoperability.

Development of SDR and its applications is underway throughout the international communities of government, industry, and academia. The European Community has been heavily funding research of major European manufacturers and universities through programs such as TRUST, SODERA, ACTS-FIRST and the Fifth Framework. Much of this work is targeted at the longer range of 4G systems and beyond, but will have applications to current 3G system development and products in the intermediate term. In Asia, organization such as KEES, ETRI-Radio & Broadcasting Technology Laboratory (Korea), and IEICE (Japan) have been active in the research and study of SDR. The SDR Forum is an international organization, consisting of more than 80 members from Asia, the Pacific Rim, Europe, and North America.

3. Interoperability (FCC NOI Questions 6-10)

Summary of Questions

How will SDR improve interoperability between systems employing different transmission standards? How can SDR facilitate future migration to new standards?

Key Motorola Messages

- ✓ SDR technology can be an important tool to improve interoperability between public safety agencies.
- ✓ SDR will allow multiregional network operators to offer wider coverage areas with fewer unique radios.
- ✓ SDR can facilitate roaming agreements between networks employing different standards.
- ✓ SDR can facilitate transition to new standard by minimizing the required investment in new hardware.
- ✓ SDR does not inherently result in moving toward uniformity in standards.

3.1: Interoperability Between Public Safety Organizations.

One of the main challenges facing public safety agencies today is the need for greater interoperability between diverse communications networks, whether it is the U.S. Department of Defense (DoD) talking to a disaster recovery agency, a federal law enforcement agency talking to a state police agency, or the National Guard talking to the local fire agency. Interoperability is especially critical in communications that support a multi-agency operation involving many levels and functions of government. These agencies may have diverse radio systems that operate in different parts of the frequency spectrum, different signaling protocols, various standards or modes of operation, and/or have different encryption algorithms. The public safety community has documented these problems and identified numerous recommendations for improving interoperability in the September 1996 Public Safety Wireless Advisory Committee (PSWAC) report. SDR is a key enabler toward achieving greater interoperability between these critical communications networks. An SDR gateway system, in which applications are configured under software control, makes it possible for public safety agencies to communicate with each other despite different physical, link, network, and upper layers, timebases, and bandwidths.

The PSWAC report documents numerous scenarios of joint government operations where communications interoperability is essential between multiple local public safety agencies, state public safety agencies, and federal government agencies. A common example is the rural wildfires that routinely occur in the western states. Such cases often involve federal agencies such as FEMA, the U.S. Forest Service, and the Army National Guard, working with state and local police agencies, local fire fighting agencies, as well as fire fighters from other states, and fire fighting aircraft. Their communications may involve many disparate, incompatible radio systems, operating in distinct spectrum bands, sometimes on different proprietary vendor protocols. The diversity of the radio systems in this scenario can include land-mobile radio systems in various federal and public safety bands and protocols (conventional, trunked, Project 25 standard and proprietary), military radio systems such as SINCGARS or Have Quick, Air Traffic Control systems, and even cellular systems.

3.2: Methods of Interoperability for Public Safety.

SDR technology will allow interoperability to be achieved in several ways. The methods used will be a function of the situational requirements. The following techniques exemplify ways in which interoperability using SDR can be implemented:

- Bridging between multiple channels employing different air interfaces.
- Universal control channel that allows a user to select a specific service according to service requirements, and then enables the equipment to implement the selected service.
- Download-enabling software tokens, entire protocol stacks, and air interfaces.
- Download processes ranging from over-the-air transmission, infrared link, from a local PC, or memory card.
- User selection among SDR library, whether by interaction with a control channel or local user interface.

One solution to interoperability is to have a federal agency such as the U.S. Forest Service set up a command center containing an SDR system to provide bridging and crossbanding between each of the radio networks. The command center would set up task force nets on the SDR that identify which specific users in each of the appropriate agencies need to communicate with each other. This is similar to the talk groups set up in LMR trunked systems. The SDR translates the voice encoding formats between each of the nets (transcoding). The SDR also translates between each of the modulation formats (Tran modulation). If privacy modes were being used, the SDR is capable of translating between the encryption algorithms used in military systems such as SINCGARS to the encryption algorithms used by the other federal, state, and local agencies. Further, the SDR could provide a multicast capability, enabling the command center to simultaneously talk to personnel in up to four separate agency networks.

3.3: Interoperability Between Commercial Networks Employing Different Standards.

SDR technology will enable multiregional network operators to offer more expansive coverage areas with fewer unique radios. SDR can also facilitate roaming agreements between networks employing different standards. Both of these benefits are predicated on the ever-increasing number of dissimilar communication standards employed nationally and globally. Given this diverse landscape, SDR, with its inherent flexibility, can provide an effective tool to bridge many technical barriers that might limit interoperability. However, technical barriers may not prove to be the limiting factor that governs interoperability between commercial networks. Business and competitive factors may dictate a level of interoperability between competitive networks that lags the technical potential.

Advanced Mobile Phone Service (AMPS), the first generation cellular standard, is still significantly used in North America today. Second generation cellular standards, such as GSM and IS-95 CDMA, have yet to reach the peak of their global deployment. The immense investment in infrastructure needed to establish these systems will result in a long period of continued global use, which may extend into the next decade. Despite the collaborative efforts of standardization partnerships such as 3GPP and 3GPP2, the emergence rate of new cellular standards is increasing. Multiple 3G standards are now being defined, and most will likely see significant industry adoption over the next five years. In addition to a multitude of air interface standards (WCDMA, IS2000, TD-CDMA, EDGE, TDD, etc.), the two dominant network protocols (MAP and IS-41) create an additional dimension of potential network incompatibility. Coupled with a global spectrum allocation plan that is not yet fully harmonized, this diverse third generation landscape will complicate an already complex global interoperability environment.

SDR can therefore serve as an effective tool, encouraging greater interoperability in such a complex communications environment. The primary enabler of greater interoperability is a subscriber unit capable of operating on networks employing multiple, incompatible standards. Examples of such subscriber products are commercially available today, such as cellular telephones that operate in multiple GSM frequency bands, and other cellular telephones that support multiple bands of CDMA in combination with AMPS. The degree of multimode, multiband capabilities in subscriber products will steadily increase, as SDR technology advances, enabling increasingly cost-effective solutions.

3.4: Interoperability: Dependencies and Uncertainties.

The degree to which SDR actually leads to greater interoperability will be very dependent upon commercial and competitive factors. As SDR evolves, both base station equipment and subscriber equipment will become increasingly common across the range of different cellular standards. This trend will likely lead to the creation of more and larger multiregional operators and partnerships. Within the context of such a cooperative scenario, SDR will clearly extend interoperability. What is less clear is the extent to which SDR will inspire interoperability between traditionally competitive networks operating within a given geographical region. It is instructive to consider current competitive markets where the only technical aspect that distinguishes the competing systems is frequency band. In these instances, subscriber units operating in one network are fully capable of operating in the competing networks. From an interoperability perspective, the technical capability of the cellular telephones is rendered irrelevant by barriers created by competitive market conditions. It is not clear, therefore, that technology advancements which overcome more challenging interoperability hurdles will actually lead to more interoperation in these situations.

3.5: Unification of Standards.

SDR will not inherently result in a movement toward uniformity in standards. It is conceivable, in fact, that the hardware adaptability inherent in SDR technology will have the opposite effect. Economy-of-scale factors that traditionally motivate industry to seek standards uniformity are likely to be minimized by the emergence of SDR. In the public safety environment as in the defense environment, SDR allows specific optimization of an air interface to a specific need. Therefore, SDR may result in a proliferation of air interface standards in specific applications for public safety. This hypothesis of standards proliferation (fueled by SDR technology) does not inherently contradict the interoperability benefits discussed earlier. The apparent paradox can be explained this way: the common platform and time to market advantages of SDR may, in fact, accelerate the emergence rate of new standards. However, the flexibility advantages of the SDR will allow products to operate over a greater number of different standards. The net effect would be improved interoperability.

3.6: Transition to New Standards.

SDR can facilitate transitions from one standard to another, or facilitate enhancement of an existing standard, by minimizing the cost of new hardware. The challenge will be producing a hardware platform that enables the implementation of any arbitrary transmission standard at a reasonable cost. Intermediate steps of SDR adoption will impose some limitations on the ability to make radical changes from one transmission standard to another. For example, it is considerably easier to develop a solution that addresses the evolution of Time Division Multiple Access (TDMA)-only systems than it is to develop a solution that addresses a transition from TDMA to CDMA technologies. Similarly, a solution that focuses only on CDMA technologies and their evolution is easier to develop than one that addresses CDMA and some other technology such as Orthogonal Frequency Division Multiplexing (OFDM).

It is reasonable that a software defined radio with programmable channel selectivity in the receiver and programmable modulation bandwidth in the transmitter could readily adapt to new technical standards. However, it cannot be said that SDR can be made "future-proof" because the hardware must be designed with certain constraints in mind. For example, the converters and data path may easily handle a change from a 25 KHz channel bandwidth to a 6.25 KHz channel bandwidth, but it may not be capable of handling a change from a 25 KHz channel bandwidth to a 2 MHz channel bandwidth. Or, it may be capable of going from a Quaternary Phase Shift Keying (QPSK) to an 8-PSK modulation, but not from a QPSK to a 256-QAM, because the precision with which the modulation is applied or extracted may not be sufficiently well balanced for this extreme case. Further, the interference conditions, such as adjacent channel and alternate channel, may not be arbitrarily changed since the converter complexity and anti-aliasing filtering would not likely be over-designed beyond reasonable margins out of cost and current-draw considerations.

In the foreseeable future, software defined radios will likely have selectable RF filters that are chosen based on the operating bands of interest. Such bands would have to be determined at the design phase of the radio. For example, if a software radio had been designed several years back, it may have accommodated 800 MHz and 1900 MHz bands in the United States, but would not likely have had the foresight to put in RF selectivity or amplifier bandwidth to operate in the new 750 and 780 MHz bands. Including selectivity for potential future bands (or otherwise increasing component complexity to operate in a band that might become available in the future), would have to be traded off with cost, size, and power dissipation considerations.

Additionally, it should be noted that new transmission standards are requiring significantly more processing power than previous generations of equipment. For example, the computational requirements for the typical third generation cellular system is about 10x that of the second generation systems. Similarly, the fourth generation digital cellular systems are expected to require another 10-fold increase in processing requirements. Similar trends can be seen in public safety and other systems as they provide ever more capability for a wider set of information transmission.

The problem of facilitating a transition to a new transmission standard will therefore become a classical cost tradeoff problem in how much excess processing capability is to be provided in the product in anticipation of future evolution of the transmission standard. This is analogous to the PC industry where new hardware platforms are continually developed with faster processor clock speeds, more memory, faster bus technology and new interface standards. New software applications ultimately require these new hardware platforms, even if the software can run on an older platform albeit at a slower speed or without the support of all of its features.

3.7: Total Cost of Ownership.

It remains to be seen at what cost ratio the market will adopt SDR if system acquisition costs are higher, while system operating, maintenance, and upgrade costs may be lower. The bridging capability of SDR will extend the lifetime of legacy systems. This feature of SDR technology is the main reason that SDR provides significant improvement in life- cycle cost of ownership over single-purpose communications equipment.

4. Spectral Efficiency (FCC NOI Questions 11-16)

Summary of Questions

How could SDR improve the efficient use of spectrum? What changes in spectral management policy are appropriate for the FCC? How and when should these changes be implemented?

Key Motorola Messages

- ✓ SDR is not a replacement for conventional spectral management policy.
- ✓ SDR will not inherently cause, nor will network systems permit, products to operate outside the context of defined network standards.
- ✓ Spectral efficiency is determined by the air interface and system deployment standards.
- ✓ SDR can enable the emergence of future air interfaces that provide improved spectral efficiency.

4.1: SDR Impact on Spectral Management Policy.

SDR is not a replacement for conventional spectral management policy; it does not remove the need for spectrum planning. Allowing ad hoc spectrum allocation, or allowing services to be placed adjacent to one another without proper consideration of interference scenarios, will not serve the public interest nor will it ensure optimal use of available spectrum.

The ability to arbitrarily locate free spectrum and utilize that spectrum efficiently is interesting, but also has significant challenges. In the most basic form, consider the ability to locate free spectrum on a slow, non-real time, basis. Such a process would be useful for locating pieces of dormant spectrum that are unused for long periods of time, perhaps on the order of hours or days. The ability to perform the same function in real-time to permit instantaneous allocation of free spectrum is considerably more complex and costly. For example, once free spectrum was located at one user's geographical location, the network would also have to determine if that same spectrum were free at other locations. Significant new development of spectrum allocation algorithms in the network is required for this to become a reality. SDR technology alone is not sufficient.

4.2: SDR Impact on Spectral Efficiency.

"Spectral efficiency", and "spectrum efficiency" are somewhat ambiguous, yet interchangeable, terms which have numerous, context specific definitions. Spectral efficiency of a single channel, described using a metric such as *bits per second per hertz,* is largely determined by the choice of a particular air interface standard, which includes the choice of modulation scheme. Whereas SDR technology does not implicitly affect spectral efficiency, it can facilitate the implementation of multiple standards that adapt the modulation formats to optimize the spectral efficiency for a given set of delivered services. Examples of commercial cellular systems that utilize adaptive forms of modulation include the iDEN system and the evolving EGPRS standard, which is derived from the GSM system, which is widely deployed throughout the world.

In iDEN, the modulation can be switched between QPSK and 16QAM depending on channel conditions that will support the desired quality of service. Similarly, EGPRS adapts to channel conditions by moving between Gaussian Minimum Shift Keying (GMSK) and 8PSK modulation. EGPRS can also adapt the amount of forward-error protection based on the channel quality to maintain an acceptable level of received bit error rate or block error rate. All of these are examples of SDR technologies that are currently in use, or will be in the near future. In much the same way, SDR, by virtue of its inherent adaptability, can enable the emergence of future air interfaces that provide even greater spectral efficiency.

4.3: Utilizing Unused Spectrum Within a Band.

Another view of spectral efficiency is the ability to instantaneously take advantage of unused spectrum within a band. This can be performed in several ways. One example is the Cellular Packet Digital Data (CDPD) packet radio system. In commercial cellular systems where CDPD is deployed, the CDPD system temporarily steals a channel once it has been released by the cellular system. The CDPD system can use that channel as long as the primary cellular RF channel is unused but must return the channel back to the cellular system when the channel is required to support the primary voice services. While CDPD is a separate overlay system to the cellular system, similar concepts are being introduced in standards for EGPRS and other future systems where gaps in speech are made available for transmitting other forms of data or in the extreme case, other speech packets. This is done dynamically but generally is confined to a given RF frequency or set of frequencies. Once again, this version of spectral efficiency is enabled only through the specific standards that govern network operation. SDR will not inherently cause, nor will network systems permit, products to operate outside the context of defined network standards.

Moving beyond a single channel, or a set of channels within a band, spectral efficiency can also be considered across multiple bands and across a large geographical area. SDR enables the possibility of networks assigning users to different bands or different modulation formats to reduce network congestion.

4.4: Interference Considerations.

As the opportunity to operate over increasingly wider ranges of RF frequencies is considered, interference scenarios must be carefully assessed between various portions of spectrum and the services operating in that spectrum. It would be extremely challenging to design a high-sensitivity data receiver that could tolerate very large signals from a television transmitter operating with EIRPs in excess of 500KW immediately adjacent to a portion of free spectrum that might otherwise be a viable option for use. Similar interference scenarios between systems of widely varying transmitted power levels, significantly different occupied bandwidths and sensitivities to varying types of interfering signals must be carefully analyzed before the Commission considers any futuristic proposals such as arbitrary, automated spectrum allocation. Significant advances in programmable filter technologies, high-dynamic range data converters and RF amplifiers, and appropriate interference mitigation techniques are all necessary before these possibilities can become viable.

Even if these capabilities were to become available, standards must be developed to define exactly how such free spectrum should be located, over what range and whether the arbitrary location and use of spectrum for a given set of services provides the desired grade of service.

4.5: Dynamic Spectral Allocation: Future Possibilities.

As SDR becomes increasingly deployed in commercial telecommunications, it may one day be possible to allow regulatory rules that would allow an operator with underutilized spectrum to make that available to other users of spectrum who might have unfulfilled demand. This dynamic redistribution of spectrum would require not only regulatory change, but also agreements on how this is technically accomplished, how it is administered, and what the terms and conditions of the spectrum exchange might be. As discussed earlier, such a concept would have serious implications to the standards applicable to incumbent uses of the effected spectrum. Establishment of new spectrum allocation processes would need to be harmonized with the creation of new standards that could tolerate, and capitalize on the new process.

5. Equipment Approval (FCC NOI Questions 17-20)

Summary of Questions

How should the current equipment approval process be modified to accommodate SDR? Should the FCC approve hardware, software, or both? Will software produced by a party other than the OEM be downloaded into a SDR?

Key Motorola Messages

- ✓ No immediate FCC rule changes are required to accommodate SDR.
- ✓ Significant software revision would be reapproved on hardware platforms as though it were a new product, minor revisions would be handled as permissible change, as is done in currently with hardware.
- ✓ Authentication and security issues must be controlled by industry to ensure that new software releases do not cause a violation of emissions and safety regulations.
- ✓ Authorized software should be certified by the OEM for use in SDR products. Industry should adopt appropriate procedures for certification.

5.1: SDR Impact on Current FCC Rules.

Motorola acknowledges the importance of making certain that spectrum be used in a way that ensures the effective operation of all services, as well as the safety of the users of those services. The FCC, and the FCC rules, play vital roles in creating and maintaining this environment. The integrity of the FCC's current policies is not inherently compromised by SDR. Therefore, no immediate FCC rule changes are required to accommodate SDR. To understand the implications of SDR on the current FCC rules, it is instructive to consider two fundamental aspects of SDR products.

First, as discussed earlier in this document, SDR will not inherently cause, nor will network systems permit, products to operate outside the context of defined network standards. The application of SDR in commercial products will only permit a device to operate in one or more predefined, standardized systems. Therefore, an SDR product must be approved for each mode of operation for which it is intended.

The second, and perhaps more interesting, aspect of SDR products will be the ability to change the software in the radio after it has been manufactured, shipped, and put into service. A new software load could, potentially, impact the emissions and safety characteristics of the unit. It is vital, therefore, that a significant software revision be re-approved on hardware platforms, just as though it were a new product. Minor revisions would be handled as a permissible change, just like minor hardware changes. Authentication and security issues must be controlled by industry to ensure that new software releases do not cause a violation of emissions and safety regulations. Authorized software should be certified by the OEM for use in SDR products. Industry should adopt appropriate procedures for certification.

5.2: SDR Impact on the Compliance Testing Process, and Regulation of Software.

The combination of hardware and software must be tested against each of the relevant specifications and standards. When additional modes are to be added, they should be tested as the combination of existing hardware and new software. The equipment manufacturer is ultimately responsible for ensuring safe and compliant operation of the equipment. Therefore, the manufacturer must employ the appropriate measures in the product design that permit only valid combinations of hardware and software to work together. These measures will be discussed in greater detail in Chapter 6.

Motorola supports open interfaces at the application layer and encourages the emergence of a vigorous and competitive third-party software market for portable wireless devices. Motorola also believes that lower-layer software interfaces should remain under the control of the equipment manufacturer. This refers to interfaces that directly affect the radio subsystem. This position is motivated by concerns over safety, reliability, security, and product performance. Software that may be loaded on a given hardware platform should be "certified" by the equipment manufacturer for the intended platform. Industry should adopt appropriate procedures for such certification.

Motorola recognizes the risks and the opportunities associated with extending open interfaces further into the radio, and intends to evolve towards radio architectures that extend the degree of radio control that is accessible from the application layer. In this way, programmers will have greater control over radio functions, while not compromising the integrity of the radio. Motorola will continue to participate in industry activity to continually refine software interface strategies so as to best address the needs of its customers.

6. Security (FCC NOI Questions 21-28)

Summary of Questions

By what means will software be downloaded? To what degree will the software interfaces in an SDR be standardized? What security measures are appropriate to protect SDRs from tampering, and what roles should the FCC and the OEM play in enforcing those measures?

Key Motorola Messages

- ✓ Software interfaces that affect emissions and safety will be controlled by equipment manufacturers.
- ✓ Security issues are extremely important; manufacturers must ensure products are tamper-proof.
- ✓ SDR does not create new or unique security issues for commercial base station equipment.

6.1: Open Interfaces.

As discussed in Chapter 5, Motorola supports open interfaces at the application layer and encourages the emerging vigorous and competitive third-party software market. Motorola believes that lower-layer software interfaces should remain under the control of the equipment manufacturer. This refers to interfaces that directly affect the radio subsystem. This position establishes the framework for a comprehensive and effective security process. Security issues are extremely important, and it is ultimately the responsibility of equipment manufacturers to ensure that their products are tamper-proof.

Many methods can and will be used to download software into a software defined radio. The range of possibilities for commercial base stations is much simpler than the range for handsets. Software download into base stations, through the Operation and Maintenance (O&M) channels of the network, has been commonplace in cellular networks for over a decade. In fact, SDR does not create new or unique security issues for commercial base station equipment.

In the case of commercial handsets, the range of possible download scenarios is much larger. Handset configuration, through downloading customized suites of applications and features, may take place at the point of distribution or the point of sale to the consumer. Software download may occur through connection to a personal computer. A current example of this is ringer melodies. A smart card or SIM card can also be used to supply software for download. Special purpose kiosks or terminals can be used. Over-the-air methods can be used. The methods will be determined by the system operators and the manufacturers.

Since the underlying hardware platforms of different commercial radio manufacturers are typically based on different processor platforms, there is little value in standardizing a software download interface for lower-layer software that directly impacts radio functionality. Such measures would only add a new level of complexity that does not give any benefit to consumers. Standardizing an interface for this type of software download would be a step towards standardizing radio implementations; therefore, so as to not stifle inventiveness, implementation should be left to manufacturers. Manufacturers should develop their own lower-layer interfaces driven by the constraints of their platforms to meet the needs of their customers.

To support the download of application software and the download of software that runs on different processing platforms, industry has already developed hardware-independent standards for software download such as JAVA, kJAVA, WAP, and MExE. Furthering this concept, industry will either adapt these existing standards or create new standards to provide a hardware-independent means of downloading lower-layer software. These methods will likely resemble the installation of plug-ins or drivers into a personal computer, where a generic interface at the application layer provides control and security for the installation of hardware-dependent, lower-layer software.

6.2: Security Issues.

The emergence of software defined radios creates the possibility for new threats to efficient and effective radio communications. There are a number of possible problems ranging from simple software defects occurring in a small number of cellular telephones to intentional software virus attacks on all phones operating in an entire cellular network. Cryptographically based methods can be used to control the probability and severity of these problems. SDR equipment manufacturers should be encouraged to use cryptography to protect software from unauthorized modification, tampering, or component failure.

6.3: User Privacy and Separation of Services.

The continued emergence of products based on SDR will highlight two privacy issues. The first is that the radio's software might be modified in a way that compromises user privacy. For example, the software could be modified to transmit private user passwords, PIN numbers, or keys. Cryptographically verifying software before it is installed and executed will prevent illegal intrusions to the software. The second concern is that inadequate separation between services on a software defined radio will compromise security. For example, a downloaded JAVA application could attempt to access private information used by another application. Manufacturers should ensure that the operating system provides sufficient isolation between software modules or services so that one service cannot access sensitive information from another service.

6.4: Security without network dependency.

SDR units that operate without continuous connection through a network present different security issues. In one respect, the security requirements for units operating independent of a network are somewhat less stringent than for units operating on a network. The overall security requirements are somewhat reduced because the network interface has been removed, and as such, is unavailable for hackers to exploit. More importantly, security in individual radios needs to be crafted in such a way so as to be independent of the network (taking a radio off the network should not make it easier to penetrate the radios defenses). That said, there are some cases where one could envision the removal of the network-hindering security. If the radios use the network as a mutually trusted authority, then units working independent of the network will be required to validate other users/radios using some autonomous method. This will certainly be workable for units that already trust one another, but could make introducing new radios difficult.

6.5: Public-Key Infrastructure.

Manufacturers have begun implementing public-key certificates in subscriber devices and development of Public-Key Infrastructures (PKI) to support e-commerce applications (using industry standards such as WAP and MExE). The security mechanisms used for e-commerce can be extended to authenticate downloads for software defined radios. The Public-Key Infrastructures would be expensive for the FCC or a TCB to create and maintain. It is suggested that each manufacturer generate the public-key based authentication codes for their products. Each SDR product that is shipped would contain the manufacturer's public key for software verification. As discussed in Chapter 5, prior to releasing signed software, the manufacture may need to obtain approval from the FCC or TCB depending on the degree of the software changes.

Motorola suggests that manufacturers cryptographically sign the program code (after receiving written approval from the FCC or TCB as needed). This allows manufacturers to reuse the Public-Key Infrastructure (PKI) that is being created to support e-commerce and other applications.

6.6: Anti-tampering Methods.

SDR equipment will potentially employ various anti-tampering mechanisms. Software downloads should be cryptographically verified before installation and execution in the SDR unit. The verification could be based on an encryption method equivalent in strength to 1024-bit RSA or 163-bit Elliptic Curve technology. The design of the SDR unit should be such that a hacker cannot bypass the verification procedure.

The most effective security features will involve a combination of both software and hardware. Techniques are being developed to bind a downloaded software component to a uniquely identified hardware platform. The binding mechanism prevents unauthorized software from interacting with the hardware. The software/hardware combination is pre-processed to self-authenticate. This eliminates the need to have a separate authentication service that focuses only on the software. It also eliminates the problem of determining how to validate the software alone. Once the software and hardware have been type-approved together, the software would be pre-processed to bind it to the hardware. The binding assures that the total integrated product will function within its specified parameters.

6.7: Method for Regulatory Enforcement.

Each SDR unit needs to provide a method for manufacturers to prove to regulator enforcement personnel that the proper software contents are loaded in a transmitter and to verify that the device meets FCC requirements. This information could be provided through the display or through a test port. The method for proving information should be left to the manufacturer, because SDR technology could be applied to a wide range of devices. The information presented should include: the manufacturer, date and place of hardware manufacture, hardware serial number, the FCC compliance identification number, and the software version number for all software modules on the product.

7. Conclusion

Motorola urges the Commission to carefully review all the comments filed in this proceeding on the underlying technologies and implications of SDR. It is our opinion, based upon both experience and ongoing research, that SDR is an important technology and one that promises significant future benefits. It is not one, however that can be identified as a quick and simple solution for complex spectrum management problems. Moreover, there is much that needs to be done before SDR can realize its potential. We urge the Commission to consider these points carefully when making policy that is dependent, in whole or in part, on the use or future development of this important technology.

Respectfully Submitted,

/S/

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APPENDIX

List of FCC NOI Questions

Question 1. What features in a radio are apt to be controlled by software? For example, could the operating frequency, output power, and modulation format be software controlled?

Question 2. What are the specific limitations of current software defined radio technology? What are the cost implications?

Question 3. What capabilities could software defined radios have that are not found in current radio technology?

Question 4. When could software defined radios be deployed commercially, and for what services or purposes?

Question 5. What work is being done on software defined radios internationally, and are there any steps the Commission should take to encourage this work?

Question 6. To what extent can software defined radios improve interoperability between different public safety agencies?

Question 7. To what extent can software defined radios improve interoperability between equipment and services using differing transmission standards?

Question 8. To what extent would software defined radios move toward uniformity in standards within or across bands.

Question 9. To what extent can software defined radios be used to facilitate transitions from one technical standard to another, such as the transition mandated by the land mobile "refarming" proceeding?

Question 10. What particular means could be employed by software defined radios to facilitate interoperability?

Question 11. To what extent could software defined radios improve the efficiency of spectrum usage?

Question 12. What particular functions related to spectrum usage could a software defined radio perform? Could it locate free spectrum, dynamically allocate bandwidth, and enable better sharing of the spectrum?

Question 13. How specifically could it carry out these functions?

Question 14. What are the benefits of the spectrum sharing arrangements described above, and what steps might we take to permit the use of software defined radios to enable such sharing arrangements?

Question 15. What changes may be appropriate for the way the Commission currently allocates spectrum?

Question 16. If changes are warranted, how could we make the transition from the current allocation and licensing model to a new model?

Question 17. Should we approve the radio hardware, the software, or the combination of them?

Question 18. Are the currently required measurements in Part 2 of the rules appropriate for software defined radios?

Question 19. How should software defined radio equipment be tested for compliance, including compliance with SAR requirements? What type of approval and labeling would be appropriate?

Question 20. Should we regulate who changes the software and the manner in which it is done? If so, should the Commission maintain records of such modifications?

Question 21. What are the various means that may be used to download new software? We anticipate, for example, that software could be downloaded by methods such as direct connection to a programming device or over the airwaves. To what extent will the software interfaces be standardized?

Question 22. Should we require anti-tampering or other security features? How would such security features work? Could equipment be designed to prevent it from transmitting in certain designated frequency bands, such as those allocated exclusively for government use, as a safeguard against causing interference?

Question 23. Do we need to adopt additional requirements for software defined radios to ensure the privacy users; communications?

Question 24. Is there a need for such an approval system, and is it feasible and practical?

Question 25. What type of authentication system should be used? Should there be one system or alternative systems? Who should have responsibility for generating the authentication codes: the FCC, TCBs, equipment manufacturers, or some other party?

Question 26. In the case of transmitters subject to verification how should authentication of software be handled? For example, could an "authentication only" service be offered in which the FCC or TCB computes the authentication code for the software after all elements of compliance with the FCC rules are verified by the manufacturer?

Question 27. How should simple changes to software be handled that do not affect the operating parameters of the equipment but require the computation of a new authentication code? Could an "authentication only" service be offered for them?

Question 28. Is there a need for a method to display information about the software loaded in a transmitter? If so, what method should be used and what information should be displayed?